

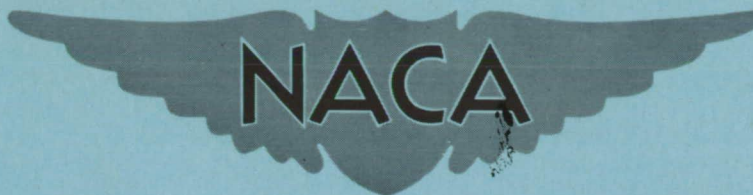
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RESEARCH MEMORANDUM

EXPERIMENTAL INVESTIGATION OF A LIGHTWEIGHT
ROCKET CHAMBER

By John E. Dagleish and Adelbert O. Tischler

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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EXPERIMENTAL INVESTIGATION OF A LIGHTWEIGHT ROCKET CHAMBER

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SUMMARY

Experiments have been conducted with a jacketed rocket combustion chamber that was fabricated by hydraulic-forming from sheet metal. Rocket combustion chambers made by this method have been used successfully. Runs with these combustion chambers have been made at over-all heat-transfer rates of 1.7 Btu per square inch per second with water cooling and also with ammonia as a regenerative coolant.

INTRODUCTION

For rocket operation beyond a few seconds duration, provisions must be made for cooling the combustion chamber surfaces. Usually this is accomplished by circulating a coolant between the combustion chamber wall and a coolant jacket wall. The high heat-transfer rates across the chamber surfaces dictate chamber walls of limited thickness and a coolant passage designed to provide a high velocity of coolant through the jacket. This entails rather critical dimensional tolerances both for the chamber wall and the coolant jacket. For flight propulsion application it is desirable that the engine weight be kept to a minimum and that one of the propellants be used as a coolant (regenerative cooling).

Rocket combustion chambers for experimental work usually are fabricated by contour machining either from solid metal or from tubular stock spun to a shape. The machining involved requires expensive specialized equipment and consumes many man-hours of highly skilled labor. Further, there are practical limitations to the wall thicknesses that can be machined.

Recently, the NACA Lewis laboratory has experimented with jacketed rocket combustion chambers fabricated by hydraulic forming from sheet metal. This fabrication method not only provides chambers with thin walls for combustion research and cooling research, but also affords relatively lightweight chamber structure.

The purpose of this report is to discuss some preliminary test results for the lightweight rocket combustion chambers formed from sheet metal. The fabrication technique is given in the appendix.

DESCRIPTION OF ENGINE

The type of jacketed rocket combustion chamber which is discussed in this report is illustrated in figure 1. The engine illustrated has a nominal thrust rating of 1000 pounds at a chamber pressure of 300 pounds per square inch. The coolant jacket comprises an inner and outer sheet metal skin. The outer skin is shaped to form four helically-wound coolant passages. In the engine illustrated these coolant passages lead directly into the rocket injection head, thus providing for regenerative cooling of the chamber.

The engine illustrated in figure 1 weighed 3.5 pounds. This is a ratio of thrust to weight of 285; therefore, this chamber assembly compares favorably in thrust-to-weight ratio with flight engines of considerably larger size.

For research purposes where engine weight is not a primary consideration, the chamber assembly is welded to a flange to permit attaching an injector and to facilitate mounting on the thrust stand.

EXPERIMENTAL TESTS

Thrust chambers fabricated by the hydraulic-forming method were tested in a brief series of firing tests. The propellants used were liquid oxygen and JP-3 with water as the coolant. These runs were up to 60 seconds in duration. The characteristic length of the chamber was 38 inches. Typical data for these runs are as follows:

Thrust, lb	Propellant flow, lb/sec	Oxidant- fuel ratio	Specific impulse, sec	Chamber pressure, lb/sq in. abs	Over-all heat transfer, Btu/sq in./sec
980	4.7	1.3	208	280	1.5
1030	4.8	1.7	216	285	1.7

Peak performance obtained was 89 percent of theoretical maximum for equilibrium expansion. All but two of nine runs with water cooling were successful. Of two burnouts experienced, one resulted when a small hole burned through a weld seam in the nozzle. This hole appears to have blocked the coolant passage, resulting in a major burnout in the cylindrical section of the chamber. The other burnout resulted from a test of an injector which caused severe burning of the injector face and which also burned through the chamber wall near the injector.

The thrust chambers have also been regeneratively cooled with ammonia, again with oxygen as the oxidant. With regenerative cooling, the coolant jacket outlet pressure is the injector inlet pressure. Thus the jacket pressure level with regenerative cooling was higher than with water cooling. This, and the fact that the coolant passage was designed for water, resulted in very high coolant jacket pressures. Two runs with chamber pressures up to 290 pounds per square inch absolute were without incident. These data are tabulated in the following table:

Thrust, lb	Propellant flow, lb/sec	Oxidant- fuel ratio	Specific impulse, sec	Chamber pressure, lb/sq in. abs	Over-all heat transfer, Btu/sq in./sec
830	---	1.1	---	255	0.9
955	4.6	1.4	208	---	1.3

During an attempt to increase the chamber pressure further, however, a failure occurred which apparently resulted when the inner wall bulged away from the outer jacket with subsequent burnout on the bulge. The jacket pressure was about 600 pounds per square inch.

DISCUSSION

The collapse of the inner wall during experimental tests with regenerative cooling points toward development work necessary with these engines. It appears that some technique of bonding the inner and outer sheets to gain support from both walls is desirable. By spot welding along the lands or contact points of the two shells, chambers which supported a hydraulic pressure of 1000 pounds per square inch in the jacket have been made. Capillary brazing of the contact points has also been used to strengthen the wall structure. The result of these strengthening techniques on the cooling effectiveness has not yet been evaluated.

Ten chambers of 1000-pound thrust rating have been made with one die which shows no wear or deterioration. Nozzle-throat dimensions have been held within ± 0.003 inches.

For the fabrication of more than one rocket combustion chamber, the technique outlined in this report has resulted in savings in time and cost over the contour machining methods that the method replaced. The total time for one chamber is about equal to that required for an equivalent machined rocket chamber. However, an additional chamber can be made with a completed die in about 10 percent of the time required for the

first chamber. Thus, it is clear that when several chambers are made, the cost per chamber is greatly reduced. Material costs are also lessened. The procedure produces very little scrap metal. Exclusive of the material in the mandrel and die, about 60 percent of the starting metal ends up in the final chamber assembly.

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APPENDIX - METHOD OF FABRICATION

The procedure for fabricating combustion chambers from sheet metal consists in forming two close-fitting coaxial metal shells over a mandrel and expanding the outer shell into a female die shaped to form the cooling passages. The outer shell expansion is accomplished by the application of hydraulic pressure.

Chamber Walls

The steps required to make the inner and outer combustion chamber walls are illustrated in figure 2 and are as follows:

The initial step is the manufacture of a two-piece mandrel, machined of steel in two parts so that it may be separated at the nozzle throat (fig. 2(a)). The mandrel is machined to the required inside diameter of the rocket combustor chamber, heat treated, and surface finished.

The inner shell, which eventually comprises the rocket combustion-chamber wall, is made of sheet metal to the approximate shape of the chamber by rolling up cones corresponding to the converging and diverging parts of the nozzle and a cylinder corresponding to the cylindrical section of the chamber (fig. 2(b)). These rolled patterns are welded together over the mandrel by the heliarc welding technique. The welded structure is then cold-formed to the shape of the mandrel on an engine lathe by use of a spinning roll (fig. 2(c)).

The outer shell, which eventually forms the coolant jacket, is similarly made of sheet metal patterns (fig. 2(d)). These patterns are rolled and welded together over the mandrel plus the first shell, which is not removed from the mandrel. The second shell is then cold spun to fit against the first shell. The two shells are welded together along the ends (fig. 2(e)). After the plaster model is made as outlined in the next section, two small tubes are sealed to the outer shell (fig. 2(f)). These tubes are for the purpose of applying hydraulic pressure between the shells; one tube serves as an air bleed. The assembly is at no time removed from the mandrel.

Die

The coolant passage die is made around the mandrel plus its two shells. This procedure assures accurate fitting between the die and the rocket body shape. The die need be made only for the first chamber; thereafter any number of chambers may be formed in the same die. The steps in making the die are diagrammed in figure 3 and are as follows:

The desired final shape of the outer chamber wall is simulated by wrapping beeswax moldings of half-circular cross sections to the outer shell of the rocket motor (fig. 3(a)). Tapered wax moldings are used where it is required to make a coolant passage of reduced section, as in the venturi section of the rocket nozzle. Thick sections are molded at the beginning and end of the chamber to form the inlet and exit coolant manifolds. Parting lines along the length of the chamber are made on the wax form by cutting slots in the wax moldings and inserting metal shims in these slots on opposite sides of the form. A bismuth-tin alloy of low melting temperature is then sprayed onto the wax and outer shell to make a female mold of the final shape of the outer shell. This mold is removed from the outer shell at the parting lines and the wax stripped from the convolutions in the mold. The two halves of the mold are placed together, with the metal shims inserted, and plaster is poured into the mold to form a male plaster model of the final outer shell shape. The low-melting-temperature metal is then melted off the plaster cast. The case is placed into an oven and dried. The plaster cast is placed into a lathe and a shell of steel is sprayed onto it by the high-temperature metallizing process.

The sprayed steel female form is centered in a thick-walled metal cylinder made of two flanged halves which can be bolted together. The two halves of the cylinder are separated by shims. An alloy metal is poured into the space between the sprayed steel form and the thick-walled cylinder to back and strengthen the steel (fig. 3(b)).

The shims between the two halves of the thick-walled cylinder are removed and the steel form is sawed apart between the flanges of the cylinder and through the center of the sprayed steel form. The plaster is removed from the two halves and new shims are made. To replace the metal removed in sawing, the new shims are cut to fit the contours of the two halves of the die (fig. 3(c)). Passages for the pressurizing tubes are cut in the die. This completes the rocket body die.

Hydraulic Forming

The mandrel with the inner and outer shells is now placed into the die (fig. 4(a)) and 5000 pounds per square inch hydraulic pressure is applied between the inner and outer shells through the tubes. The pressure expands the outer shell to form the coolant passages and, upon removal of the die (fig. 4(b)), the rocket chamber assembly is essentially complete. It is only necessary to remove the pressurizing tubes and to weld on tubes to conduct the coolant to and away from the rocket motor. A 1000-pound thrust rocket combustion chamber is shown being removed from the die in figure 5.

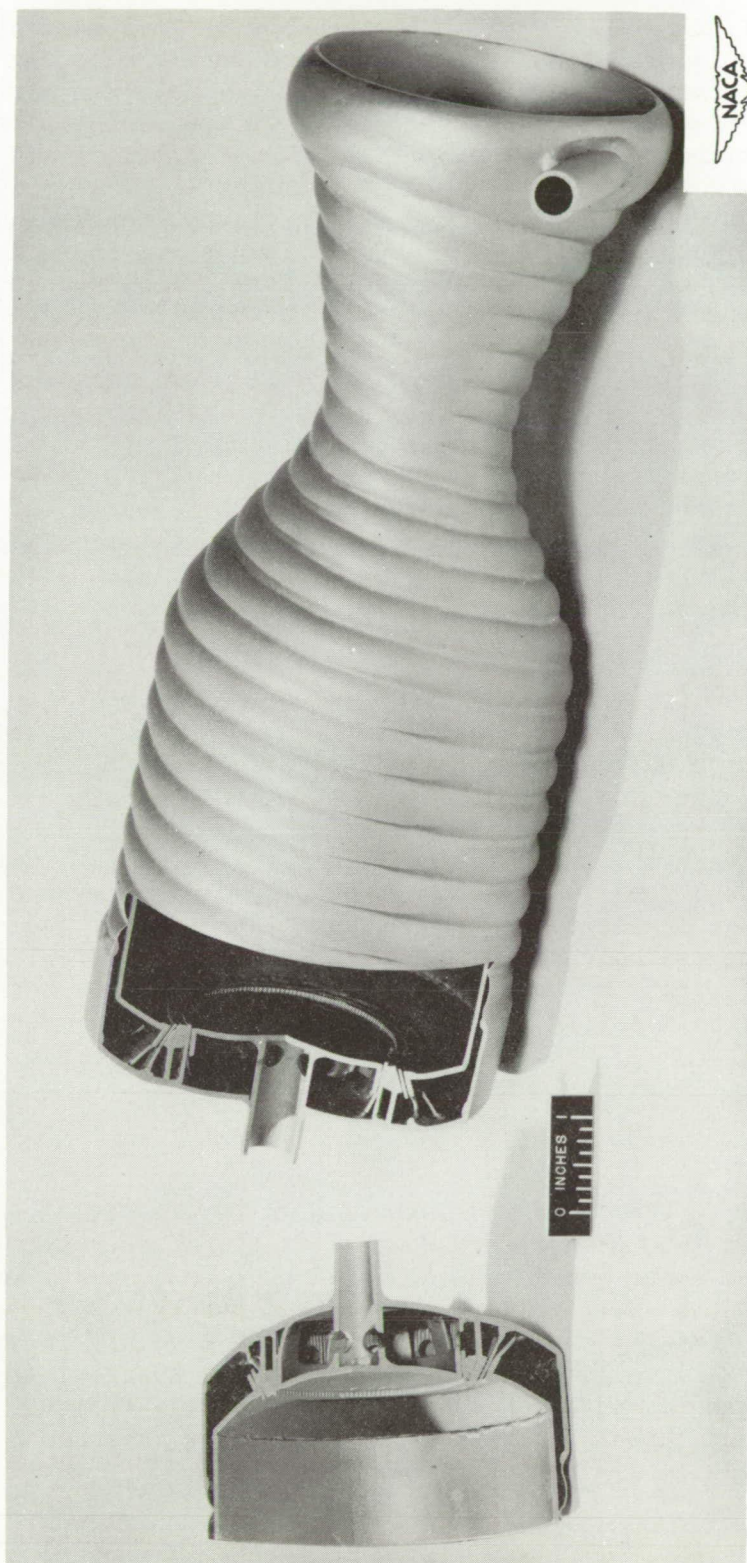
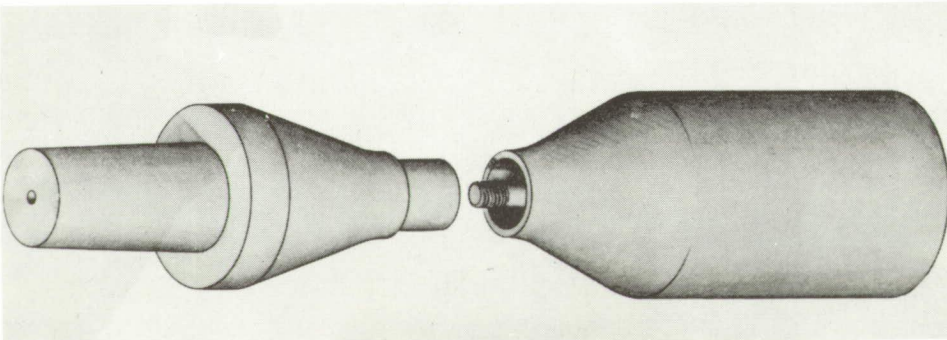
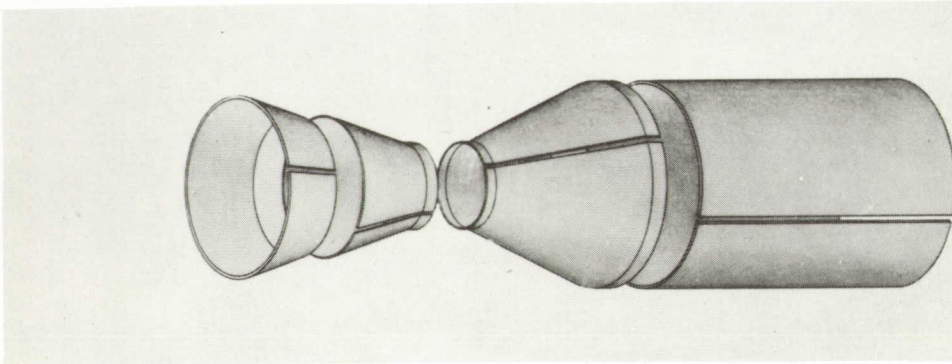


Figure 1. - 1000-pound thrust chamber equipped with injector to use regenerative coolant.

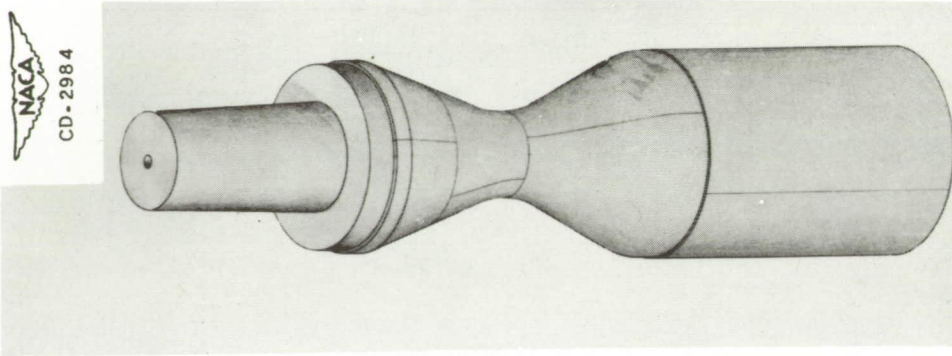
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(a) Two-piece solid steel mandrel.

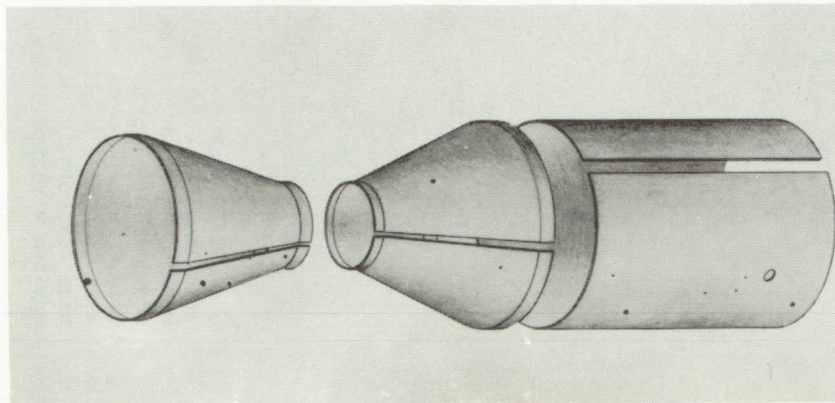


(b) Inner sheet-metal shell components.

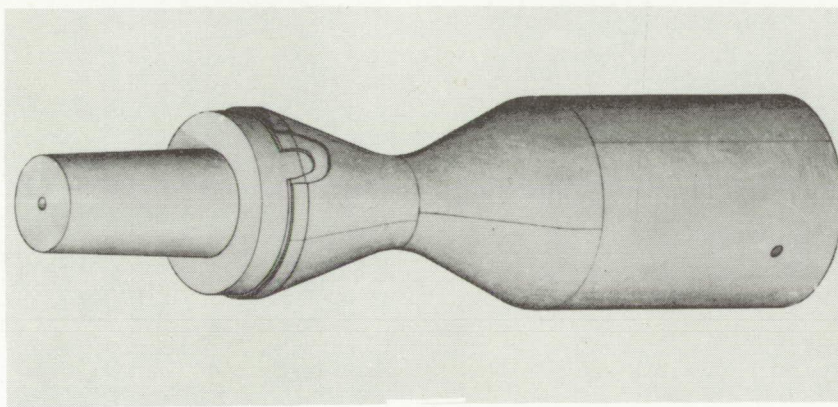


(c) Inner shell components heliarc-welded together and cold-formed to mandrel.

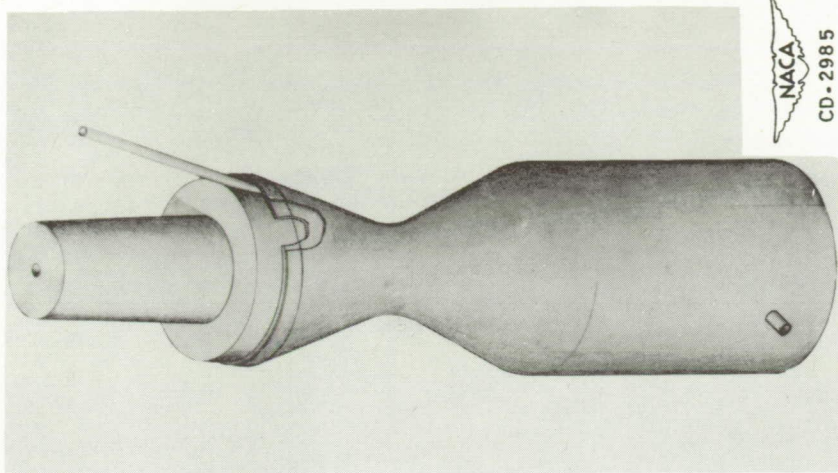
Figure 2. - Initial steps in fabrication of chamber walls for lightweight rocket chamber.



(a) Outer shell components.



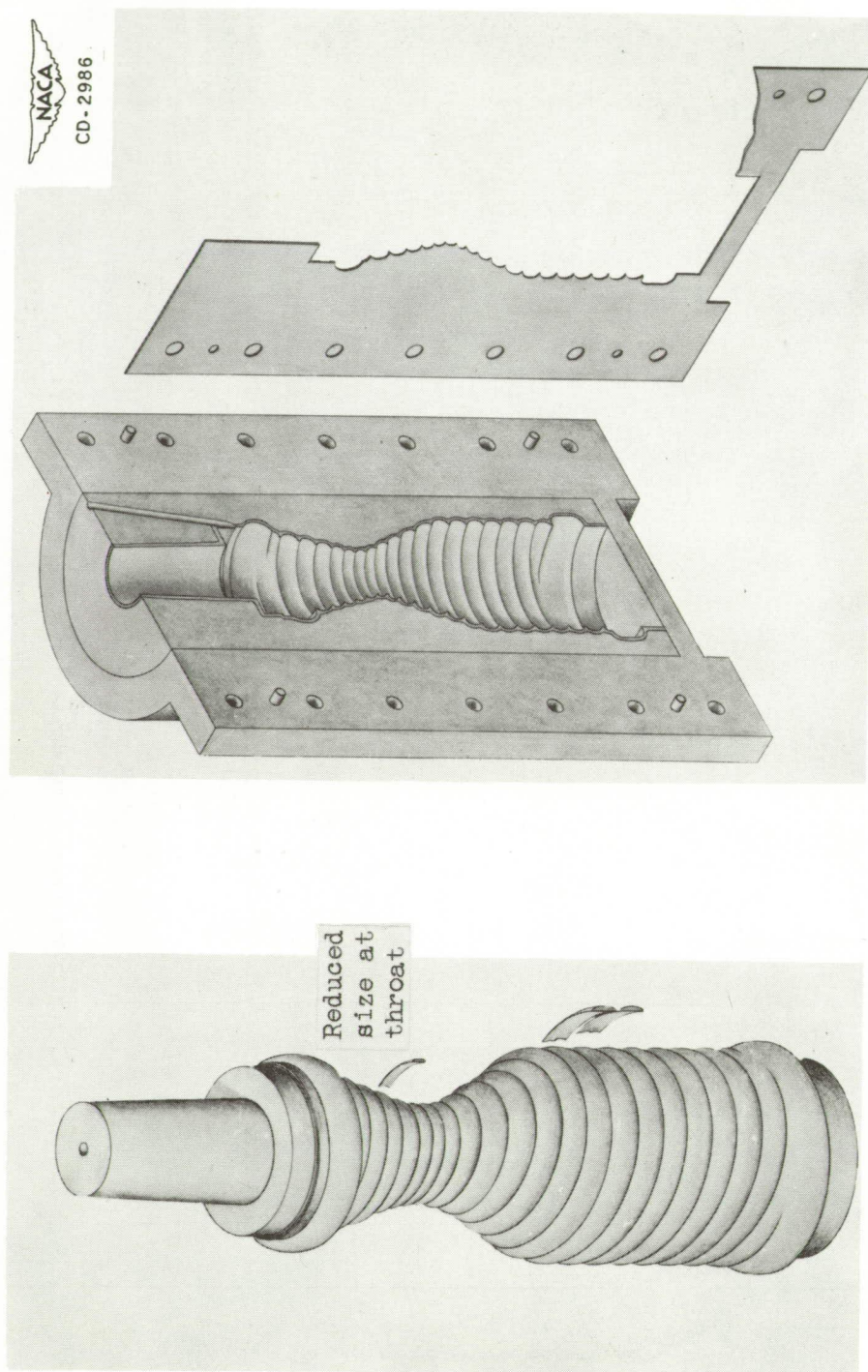
(e) Outer shell components welded together and cold-formed metal-to-metal on inner shell and mandrel. Inner and outer shells welded together along upper and lower edges.



(f) Tubes, 1/4 inch, welded to shells for hydrostatic pressurizing after preparation of transfer mold. Transfer mold necessary only for preparation of die.

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Figure 2. - Concluded. Initial steps in fabrication of chamber walls for lightweight rocket chamber.



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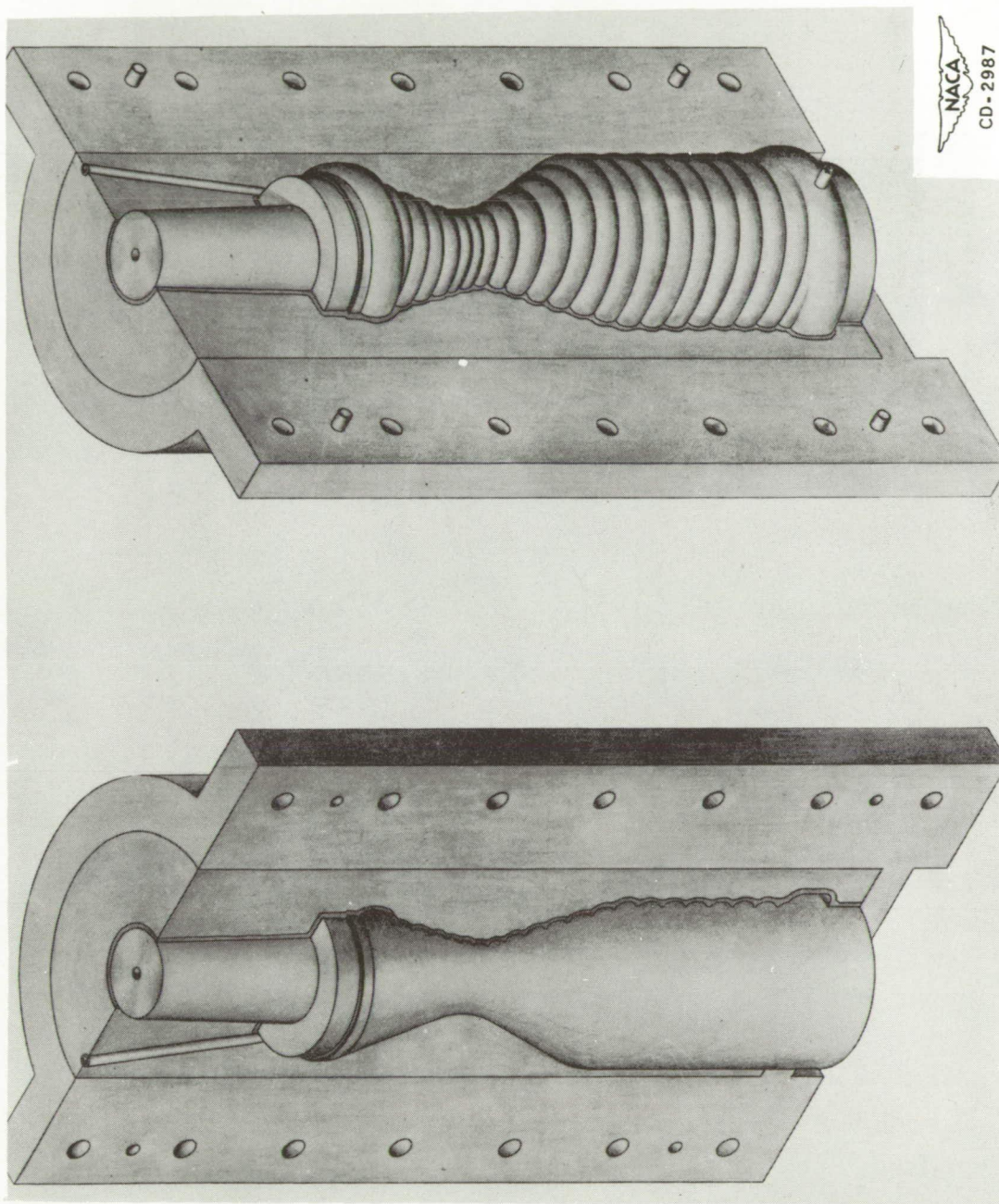
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(c) Metal lost in saw cut replaced by shim.

(b) Metal-coated plaster cast is placed inside heavy wall steel jacket and surrounding volume filled with alloy metal. Jacket and contents are sawed in half on the center line forming a split die.

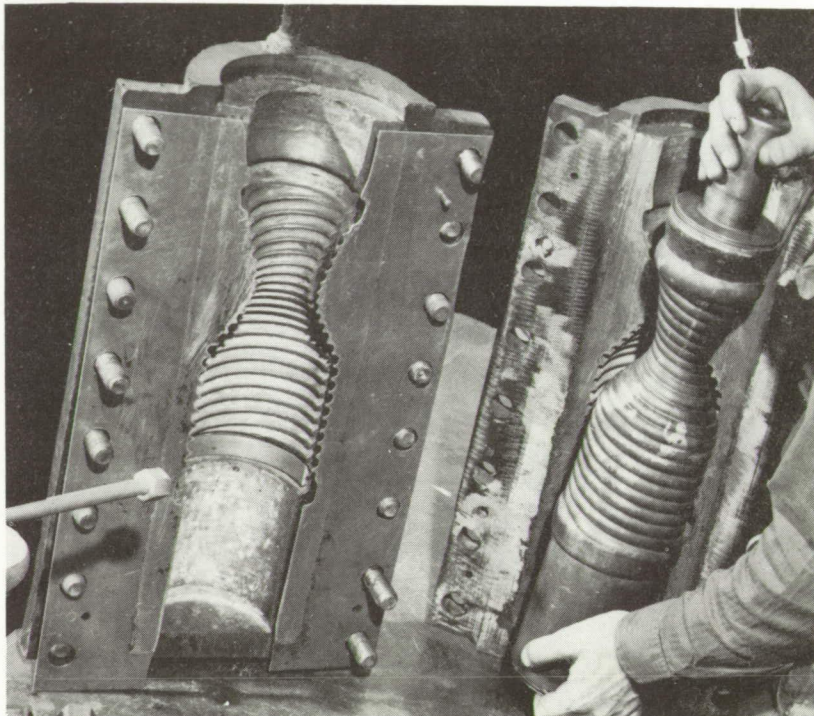
(a) Solid beeswax cooling passage molds applied over shells on mandrel. Female mold made in low-melting alloy from this body. Male plaster master cast in female mold. Male plaster cast covered with steel shell applied with metalizing gun.

Figure 3. - Preparation of die.



(a) Mandrel with inner and outer shells placed in die. (b) Rocket body after 5000 pounds per square inch has been applied between inner and outer shells.

Figure 4. - Hydraulic forming of coolant passages.



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Figure 5. - Removal of 1000-pound thrust chamber from die..

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